

Some Results from the Demonstration of
Indoor Radon Reduction Measures in
Block Basement Houses

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Abstract

Active soil ventilation techniques have been tested in 24 block-wall basement houses in eastern Pennsylvania having significantly elevated indoor radon concentrations, generally above 740 becquerels per cubic meter (Bq/m^3). The results indicate that radon levels can be reduced substantially (often below the U.S. Environmental Protection Agency (EPA) guideline of 148 Bq/m^3) if effective suction can be drawn on the soil underneath the concrete slabs of these houses. Such effective suction appears achievable when either: a) the house has a complete loop of drain tile around its footings for water drainage purposes, and suction is drawn on that loop; or b) a sufficient number of suction pipes can be inserted at the proper locations into the crushed rock or the soil underneath the slab.

Introduction

This paper describes some of the results from a project being conducted for EPA by AMERICAN ATCON, involving the testing of developmental indoor radon reduction techniques in houses located in the Reading Prong region of eastern Pennsylvania. The primary objective of this project is to develop and demonstrate cost-effective techniques for the conditions representative of that region; i.e., for houses where: indoor radon levels are very high (above $75,000 \text{ Bq/m}^3$ in extreme cases); infiltrating soil gas is the predominant source of the indoor radon; and the prevalent substructure type involves a full or partial basement with a concrete floor slab and with foundation walls often constructed of either hollow construction blocks or poured concrete, sometimes with an adjoining slab-on-grade or crawl-space wing.

Active soil ventilation was selected as the primary radon reduction approach to be tested in most of these houses, because it appears to offer the potential for achieving (at moderate cost) the very high reductions in soil gas influx which are required. Active soil ventilation involves the use of one or more fans to draw suction on (or to blow outdoor air into) the soil around the foundation of the house in an effort to divert the radon-containing soil gas. If the soil ventilation system is operated in suction, as with the systems described here, then it will be effective only if it is able to maintain soil gas pressure near all major entry routes at a level lower than that inside the house. The major entry routes in basement houses having hollow-block foundation walls generally include any openings through the slab and walls (also including any openings where soil gas can enter the void network inside the block wall, which can serve as a conduit for the soil gas into the house). To achieve ade-

quate suction at all of the these entry routes, the soil ventilation system requires a suitable combination of: a) suction points located sufficiently close to the entry routes; b) reasonable permeability (e.g., in the soil and crushed rock underneath the slab) so that entry routes remote from the suction points are treated; c) sufficient suction in the system (i.e., a fan capable of a reasonable static pressure at the soil gas flows encountered), so that suction will be distributed remote from the suction points; and d) closure of major openings in the slab and walls, so that fan suction is not lost through the leakage of house air into the suction system through these openings.

In most of the testing reported here, the fans utilized have been units capable of moving 127 L/sec at zero static pressure, and capable of developing over 250 Pa static pressure before stalling.

Measurement Methods

Radon gas is measured using a Pylon Model AB-5 semi-continuous radon monitor, equipped with a 285 mL Lucas scintillation cell. The Pylons are programmed to make hourly measurements, and are generally operated in each house for at least 48 hours (and sometimes as long as 96 hours) both before and after the radon reduction technique is activated. These measurements are always made in the basement of the house with all basement doors and windows closed.

Three-month integrated measurements during winter months using alpha-track detectors are made in all houses following completion of the mitigation installations.

Results

Sub-slab suction via drain tiles

Some houses contain perforated drain tiles around the outside or inside of the perimeter footings for water drainage purposes. If present, such tiles are ideally located to permit suction to be drawn near some of the major soil gas entry routes for houses with block foundation walls; i.e., the joint between the slab and the foundation wall, and the footing region where soil gas can enter the void network inside the walls. In addition, suction drawn on the tiles might extend underneath the entire slab. If the tiles drain to an above-grade discharge or a dry well, the underground line of tile leading to the discharge is water-trapped and connected to a fan at grade level through a riser pipe. If the tiles drain to an interior sump, the sump is capped and vented. EPA's guidance document, "Radon Reduction Techniques for Detached Houses" (EPA/625/5-86/019, June 1986), further describes these and other approaches.

The current results from testing this technique in block basement houses are summarized in Table 1. The Pylon results before and after activation of the technique are presented in the table both as the range of the hourly measurements, and as the arithmetic mean of the measurements. In all cases where the drain tiles formed a complete loop around the house, substantial radon reductions have been achieved, often reducing indoor concentrations below 148 Bq/m³. The only cases where houses with complete loops had excursions above that level after activation (Houses 10 and 27) involve situations where an interior load-bearing hollow-block structure penetrates the slab, providing a potential major soil gas entry route through the slab remote from the perimeter drain tiles. When the drain tiles do not form a complete loop, Table 1 shows that performance is reduced, probably because some segment of the footings and

sub-slab are not receiving adequate suction. A higher-suction fan might have yielded better results in Houses 14 and 16. The tile networks connecting to the sumps in Houses 17, 28, and 29 might be quite limited.

Sub-slab suction via pipes through slab

Another approach for drawing suction on the soil underneath the slab is to drill holes through the slab at appropriate locations inside the house and to insert pipes into the crushed rock or the soil under the slab. Suction is then drawn on these pipes, and the collected soil gas is vented outdoors.

Table 2 presents the Pylon results obtained to date in this study using that approach in block basement houses without French drains. As shown, if a sufficient number of suction points are installed in the basement slab, and if these points are located near the perimeter joint between the slab and the foundation wall, substantial reductions have generally been achieved (often 90% and greater, reducing some very high-radon houses to 148 Bq/m^3 and less). With a suitable number and positioning of the points, there is an increased likelihood that the suction will be distributed underneath the entire slab, treating all of the major entry routes, and that, in particular, soil gas movement up into the void network inside the block walls (and up through the wall/floor joint) can be prevented. The houses which have a number of perimeter suction points but which still average above 148 Bq/m^3 have at least one wall without a slab suction point nearby (Houses 6B and 20A) and/or do not yet have one of the high-suction fans (Houses 7B and 20A). As shown in Table 2, when the number of suction points is more limited, and when the points are placed remote from the wall/floor joint, radon reductions can be less predictable, because portions of the slab are not always adequately treated (especially the wall/floor joint and the footing region). None of the houses having a limited number of centrally located suction points (Houses 1, 2, 3, 4, and 20) had high-suction fans, nor were slab and wall openings generally closed; thus, these factors, as well as the number and location of suction points, might have contributed to the poorer performance in those houses. As shown by House 21, even a limited number of suction points can sometimes give good performance if factors b), c), and d) listed in the Introduction are sufficiently favorable (and, perhaps, if the points are near the most important radon entry routes). The results with House 1 (where the slab was poured directly on the granite bedrock) confirm that, even with multiple suction points, some reasonable sub-slab permeability is required if this approach is to achieve good reductions with a reasonable number of suction points. With most of the houses in Table 2, additional suction points, strategically placed and with sufficient fan suction, would probably have improved radon reduction performance.

Conclusions

1. If a complete loop of perimeter drain tiles is present, suction on this loop should be one of the first reduction approaches considered because: a) the tiles permit suction to effectively be drawn where it is generally needed the most in houses with hollow-block foundation walls, and high reductions are often achieved; b) drain tile suction is generally the least expensive of the active soil ventilation approaches, and is the most amenable to do-it-yourself; and c) where tiles drain to a point outside the house, the entire installation is outdoors, thus offering advantages in convenience and aesthetics. Unfortunately, complete loops are not always present.

2. Even where only a partial drain tile loop exists, drain tile suction can provide some reduction and, under some circumstances, might still be a cost-effective measure to install before attempting additional measures.
3. Sub-slab suction using pipes penetrating the slab from inside the house can be very effective in houses with hollow-block foundation walls, if good suction can be drawn under the entire slab (especially in the vicinity of the footings and the wall/floor joint). One way to help ensure such effective suction appears to be to place one or more suction points near each load-bearing block wall (including interior as well as perimeter walls); i.e., near major suspected soil gas entry routes. In some cases, it might also be necessary to include a suction point near a potentially important entry route away from the perimeter; e.g., near a cold joint in the slab. The actual number and location of the required suction points will be determined by the nature and uniformity of the permeability underneath the slab, by the location of the major radon entry routes, and by the presence of openings which cannot be closed and hence create a loss in suction. Diagnostic testing of the permeability and pressure distribution before installation could aid in the design of the system.
4. With any active soil ventilation technique, it is crucial that major openings in the slab and wall be closed, in order to permit effective suction to be drawn as well as to reduce soil gas entry. In addition, floor drains connecting to the soil should be trapped or plugged, and sumps should be capped even if suction on the sump is not planned. In houses having French drains that cannot be closed, the active soil ventilation system must be designed to address this feature (see EPA/625/5-86/019).
5. With any of these sub-slab techniques, best results have been achieved when the fan being used is capable of maintaining at least 170 Pa at the suction points with the soil gas flows encountered (typically 20 to 70 L/sec).

Table 1. Results with suction on drain tiles (block basement houses)

House No.	En Levels with System Off (Bq/m ³)		En Levels with System On (Bq/m ³)		Percent Reduction In Mean	Comments
	Range	Arith. Mean	Range	Arith. Mean		
<u>Drain tiles completely surround house</u>						
10	3,400-11,400*	7,400*	70-550	250	97	200 Pa suction in riser to fan. Interior block wall penetrates slab. 120 Bq/m ³ measured using Track Etch during winter after system activated, but with moderate-suction fan (70 Pa in riser).
12	220-740*	440*	70-130	100	77	210 Pa suction.
15	180-1,810*	670*	15-140	40	94	170 Pa suction. 140 Bq/m ³ measured using winter Track Etch after system activated, but with moderate suction fan (70 Pa).
26	1,180-7,070*	3,310*	15-70	40	99	210 Pa suction. New slab poured in previously unpaved fruit cellar.
27	670-2,370*	1,550*	40-330	110	93	320 Pa suction. Hollow-block structure penetrating basement slab supports fireplace on first floor.
<u>Drain tiles do not completely surround house</u>						
13	2,220-3,260*	2,660*	150-630	420	84	250 Pa suction. Concentrations in house occasionally swell to 740-920 Bq/m ³ over 4 hours.
14	1,960-2,480*	2,220*	300-850	580	74	40 Pa suction (low-suction fan).
16	5,030-12,100*	8,880*	3,030-8,140	5,580	37	100 Pa suction (moderate-suction fan).
17	920-1,630*	1,180*	480-850	670	43	About 25 Pa suction (moderate-suction fan). Tiles of uncertain extent under slab drain to sump; suction drawn on sump.
28	**	~ 800	380-2,500	800	~ 0	70 Pa suction (moderate-suction fan). Tiles of uncertain extent drain to sump; suction drawn on sump.
29	150-3,330*	1,740*	180-810	500	71	60 Pa suction (moderate-suction fan). Tiles of uncertain extent drain to sump; suction drawn on sump. Adjoining earth-floored crawl space open to basement, covered with vented liner.

* All measurements were obtained during cold-weather months (November through March) except those marked with an asterisk. Radon levels would be expected to be highest during cold weather due to increased thermal stack effect, and to tendency of house to be closed.

** Insufficient data to determine reliable range.

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Table 2. Results with suction underneath concrete slab (basement houses with hollow-block foundation walls, with no adjoining slab on grade)

House No.	En Levels with System Off (Bq/m ³)		En Levels with System On (Bq/m ³)		Percent Reduction In Mean	Comments
	Range	Arith. Mean	Range	Arith. Mean		
<u>Installations involving multiple individual sub-slab suction points distributed beside foundation walls.</u>						
4A	550-900	740	40-160	100	86	6 suction points distributed around perimeter wall (17 m ² of slab area per suction point). 220 Pa suction in each suction pipe near slab. Openings in slab, top voids in wall closed. 2-hour spike to 270 Bq/m ³ during system operation.
6B	1,300-3,610	2,210	100-220	180	92	3 suction points around only half of perimeter due to wall, floor finish in other half (36 m ² per suction point). 170-210 Pa suction in each pipe near the slab. Cold joint in slab closed. 5-hour swell to 400 Bq/m ³ during operation.
7B	5,750-23,150	14,890	30-240	120*	99	6 suction points around perimeter walls plus 1 point near interior load-bearing block wall (14 m ² per point). About 40 Pa suction in each pipe (moderate-suction fan). Openings in walls (incl. top voids) and slab closed.
13A	2,220-3,260*	2,660*	20-150	80	97	4 suction points around perimeter walls (24 m ² per point). 140-170 Pa suction in each pipe. Drain tile suction system (House 13 in Table 1) also in operation.
20A	5,460-25,750	10,440	140-770*	480*	95	5 suction points around three of the perimeter walls, one wall <u>not</u> treated (19 m ² per point). 90 Pa suction in each pipe (moderate-suction fan). Openings in wall and slab closed.
31	15,510-19,490	17,945	80-240	130	99	6 suction points around perimeter (19 m ² per point). 250 Pa suction in each pipe. Solid cap blocks close top voids in block walls.
33	110-410	210	20-100	45	79	6 suction points around perimeter plus 1 central point in well-head pit inside basement (15 m ² per point). 220-250 Pa suction in each pipe.

(continued)

(continued)

Table 2.(cont'd) Results with suction underneath concrete slab (basement houses with hollow-block foundation walls, with no adjoining slab on grade)

House No.	Rn Levels with System Off (Bq/m ³)		Rn Levels with System On (Bq/m ³)		Percent Reduction In Mean	Comments
	Range	Arith. Mean	Range	Arith. Mean		
<u>Installations involving one or two individual sub-slab suction points, generally not beside foundation walls.</u>						
1	4,660-7,360*	5,950*	4,000-6,960*	5,000*	16	2 suction points centrally located, one approximately in the center of each half of the slab (51 m ² per suction point). About 70 Pa suction (moderate-suction fan). No crushed rock found under slab. Smoke stick air flow testing around slab suggested that suction was not extending under slab.
2	3,260-18,610*	8,810*	1,110-2,150*	1,760*	80	2 suction points, one approximately in the center of each half of the slab (63 m ² per point). About 70 Pa suction (moderate-suction fan). Good crushed rock under slab. Smoke stick testing indicated that suction was not extending to one end of slab. No closure of slab cracks.
3	31,380-54,580*	44,590*	18,650-21,050*	19,460*	56	1 suction point in center of slab (56 m ² per point). About 70 Pa suction (moderate-suction fan). Reasonable crushed rock.
4	**	~ 1,480*	670-1,040	820	~ 45	2 suction points, are approximately in the center of each half of the slab (50 m ² per point). About 250 Pa suction. Limited crushed rock under slab. Smoke stick testing suggested suction was not extending under slab. No closure of slab openings. Installation replaced by sub-slab suction system having multiple perimeter suction points (House 4A above).
20	5,460-25,750	10,440	740-2,920	1,600	85	2 suction points, one approximately in the center of each half of the slab (47 m ² per point). About 70 Pa suction (moderate-suction fan). No closure of slab or wall openings. Installation replaced by larger sub-slab system (House 20A above).
21	1,410-7,440	4,100	40-150	100	98	1 suction point near one of the end walls (93 m ² per point). 300 Pa suction in pipe. No closure of wall openings (top voids) concealed by panelling.

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